Precision based guidelines for sub-maximal normalisation task selection for trunk extensor EMG

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A B S T R A C T

Aim: The object of this study was to quantify the contribution of sub-maximal normalisation to the overall variance of exposure parameters describing erector spinae (ES) activity, and to provide guidelines for task selection which minimize methodological variance.
Methods: ES EMG was measured from three locations (T9, L1 and L5 levels) on fifteen men performing a manual materials handling task in the laboratory on three separate days. Four repeats of each of eleven sub-maximal normalisation tasks (eight static, three dynamic) were collected, work data were normalised to each task and repeat, and exposure parameters calculated. The unique contribution of normalisation to the overall variance was determined for each task and exposure parameter using variance component analyses. Normalisation tasks were scored according to their relative contributions to the overall variance and coefficients of variation.
Results: A prone task, similar to the Biering-Sørensen test posture, was the most repeatable for all electrode locations and across all exposure parameters. Thoracic level normalisation typically showed poorer repeatability than lumbar normalisation.
Discussion: To maximize measurement precision, we recommend that future ES EMG studies employing sub-maximal normalisation utilise said prone task. An alternate normalisation task specific to thoracic level ES muscles may be warranted.

1. Introduction

Electromyography (EMG) is frequently used to quantify exposure in studies examining occupational risk factors for low back pain. EMG data are typically normalised. This serves to: reduce signal variability due to individual physical characteristics unrelated to muscle activity (for example, the thickness of the tissue overlying the muscle); produce biomechanically meaningful values (Mirka, 1991); and to provide a standardized scale to permit comparisons between subjects, days, conditions and/or studies (Mathiassen et al., 1995).

Historically, trunk muscles have been normalised using maximum voluntary exertion (MVE) tasks (Mirka, 1991), however sub-maximal reference voluntary exertion (RVE) tasks have shown increased sensitivity for assessing low levels of muscle activity

(Allison et al., 1998; O'Sullivan et al., 2002; Snijders et al., 1995) and to be more reliable and feasible among low back pain patients (McGill, 1991; O'Sullivan et al., 2002). A wide range of sub-maximal normalisation tasks has been used for studying the trunk extensor muscles. A survey of erector spinae (ES) EMG literature from the last 25 years shows that tasks can be grouped into three gross body postures: standing (for example (Lariviere et al., 2002; McGill, 1991; Mirka and Marras, 1993; Ng et al., 2002)), sitting (for example (Elfving et al., 1999; Larivière et al., 2008; Roy et al., 2003)), and prone (for example (Dankaerts et al., 2004; Gregory et al., 2006; McGill, 1991; McGill et al., 2006; van Dieen et al., 2001)), with multiple tasks reported within each posture group. To date, minimal guidance has been provided regarding RVE task selection.

While normalisation will reduce some sources of variance in EMG studies, the methodological process of normalisation will itself introduce a random error component due to the inherent motor variability associated with repeatedly performing any task (Jackson et al., 2009; Nordander et al., 2004). One key criterion that

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could aid in normalisation task selection would be to identify which task(s) contribute least to the overall exposure variance. Such data are currently lacking.

The aims of this study were therefore: (i) to quantify the unique contribution of normalisation to the overall variance for a comprehensive set of sub-maximal normalisation tasks previously used in EMG studies of the ES muscles; and (ii) to provide guidelines to support the selection of a proper normalisation task from the perspective of minimizing methodological variance.

2. Methods

2.1. Participants

Males aged 18–55 were recruited from the greater Boston area using an online classified advertisement. Interested parties completed a health questionnaire over the telephone. Applicants were excluded if they: reported a history of chronic low back pain (LBP); had experienced LBP in the preceding 12 months; and/or had any other medical conditions that would prevent them from comfortably performing typical manual materials handling tasks for an eight-hour work day. To try and maximize EMG signal quality, applicants were also excluded if their self-reported height and mass gave a body mass index (BMI) estimate greater than 30, a value which corresponds to the classification of 'obese'. All participants reviewed and signed information and consent forms that were approved by both the Internal Review Board at the Liberty Mutual Research Institute for Safety and the Office of Research at the University of Waterloo.

The mean age of the 15 male participants who completed the study was 31.8 years (SD 10.8, range 20–50), height 1.78 m (SD 0.11, range 1.52–1.93), weight 79.6 kg (SD 13.2, range 52.3–97.7), and BMI 25.1 kg m^{-2} (SD 3.5, range 20.1–29.8).

2.2. Study protocol

All participants completed a three-day protocol, with a minimum of one rest day between scheduled visits. On the first day, participants were taught the difference between hip flexion and lumbar spine flexion via verbal description and live demonstration and subsequently performed both movements until both the experimenter and participant believed the participant understood the movements. This was crucial as pure hip flexion was desired for all normalisation task postures to ensure a comparable spinal posture and relative location of the electrodes to the underlying muscle fibres across tasks. Next, the participant was taught and practiced each normalisation task until they felt comfortable performing the task – see Section 2.3, Fig. 1 and Table 1. Following a 30 min paid break, participants began the experimental protocol which was consistent across all three days.

Participants were instrumented with EMG electrodes and motion capture markers and then performed 10 cycles of a lift-carry-lower-return (LCLR) manual materials handling task as a warm up (no data were collected for these trials). Participants then completed four repeats each of all normalisation tasks (Section 2.3) followed by a manual materials handling task (Section 2.4).

2.3. Normalisation tasks

Normalisation tasks were performed in three gross body postures: prone, seated, and standing. In sitting and standing, normalisation tasks were performed at two different trunk flexion angles (0 and 20° for sitting, and 20 and 50° for standing) – Fig. 1 and Table 1. Normalisation postures were selected based on: (i) regular appearances in the literature; (ii) potential applicability to clinical
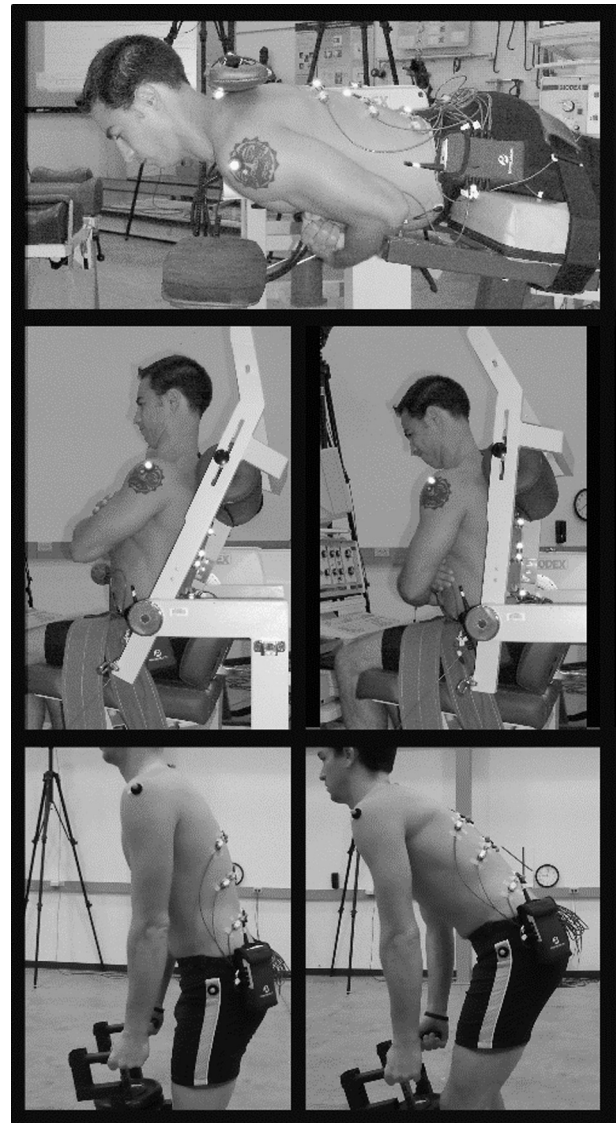

Fig. 1. Normalisation task postures: top = *prone*; middle left = $Sit_{0°}$ 30%MVF; middle right = $Sit_{20°}$ 30%MVF; bottom left = $Stand_{20°}$ 10kg; bottom right = $Stand_{50°}$ 10kg. Body weight only standing trials were performed without the 10 kg jig.

populations; and (iii) relevance according to a physiological criterion - for example, 50° trunk flexion was selected as it is the angle at which maximal male trunk extension strength has been shown to occur within the 0–50° trunk flexion range (Roy et al., 2003). .

Normalisation tasks were presented in a block-randomized order where gross body posture (prone, sit, stand) formed the blocks; within each block, the order of the individual tasks was randomized to the extent possible. For all seated tasks, maximum voluntary exertion (MVE) trials were performed prior to the respective sub-maximal task to determine the relative benchmark exertion levels. Four sequential trial repeats were performed for all normalisation tasks. Submaximal trials were 10 s in duration and were interspaced with 30 s rest. A minimum of 1 min of rest was given between tasks. A longer break was given between blocks of tasks during which time the participants transitioned to a different physical location in the laboratory and next body posture.

For prone trials, participants were strapped firmly to a padded bench, which supported their lower body – Fig. 1. A wheeled stool was provided under the upper body to provide rest prior to- and between trials. A bar was adjusted over the scapulae so each

Table 1

Summary of sub-maximal normalisation tasks. Sit and Stand postures show the angle of the trunk with respect to the vertical following flexion at the hip. MVF = maximum voluntary force.

Name	Description	Calculation method	Key reference(s)
Static tasks			
Prone	Lying prone with the lower body securely supported and the upper body actively held in a neutral trunk posture by maintaining constant contact with a bar positioned across the shoulders (upper body weight only)	Mean of 10 s trial	c.f. Biering– Sørensen test (Biering-Sørensen, 1984)
Sit_0 30% MVF	Seated upright at 0° trunk flexion, constant extension exertion at 30% of the maximum extension previously measured in the same posture	Mean of 10 s trial	c.f. (Roy et al., 2003)
$Sit_{20°}$ 30% MVF	Seated in 20° trunk flexion, constant extension exertion at 30% of the maximum extension previously measured in the same posture	Mean of 10 s trial	c.f. (Roy et al., 2003)
$Stand_{20°}$BW	Standing in 20° trunk flexion, arms hanging vertically, body weight only	Mean of 10 s trial	To compare with $Sit_{20°}$ 30%MVF
$Stand_{20°}$ 10kg	Standing in 20° trunk flexion, arms hanging vertically, 10 kg jig held evenly between the hands	Mean of 10 s trial	To compare with $Sit_{20°}$ 30%MVF
$Stand_{50°}$BW	Standing in 50° trunk flexion, arms hanging vertically, body weight only	Mean of 10 s trial	c.f. (Dunk, 2009)
$Stand_{50°}$ 10kg	Standing in 50° trunk flexion, arms hanging vertically, 10 kg jig held evenly between the hands.	Mean of 10 s trial	c.f. (Dunk, 2009)
$Stand_{50°}$ 10kg.EB	Standing in 50° trunk flexion, as determined by 'eye ball' estimation to align trunk angle with a marked angle on the wall, arms hanging vertically, 10 kg jig held evenly between the hands	Mean of 10 s trial	c.f. (Dunk, 2009)
Dynamic tasks			
TT_{ALL}	Full trunk range of motion movement from upright to toe touch and up again following a metered, verbal count to direct the movement timing.	Mean of 10 s trial, including upright rest pre- and post-movement	–
TT_{move}	Full trunk range of motion movement from upright to toe touch and up again following a metered, verbal count to direct the movement timing.	Mean of the window containing only the toe touch movement	–
$\overline{LCLR}$	One lift-carry-lower-return (LCLR) work cycle	Mean across 15 s cycle	–

participant would feel the bar once they had achieved the desired neutral trunk posture; participants were instructed to maintain gentle contact with the bar throughout the trial.

For seated tasks, participants sat in the positioning chair of a dynamometer machine (*Biodex Medical Systems Inc., Shirley, New York, USA)* with the centre of rotation of the Biodex back extension/flexion attachment unit aligned as closely as possible with the estimated centre of rotation of the L4/5 joint. Participants were strapped firmly to the machine at two locations – Fig. 1.

For standing tasks, participants were meticulously guided to each set angle and continuously monitored by a research assistant using an electric goniometer. A less meticulous approach was taken for the $Stand_{50°}$ BW-EB ('eye-ball') trial in which the research assistant verbally guided participants to the desired angle by matching ('eye-balling') their trunk angle to a 50° angle marked on the wall behind the subject. Since no physical 'stop' or 'guide' was used to mediate task posture during standing tasks (as was used in prone and sitting tasks), mean trunk angles for each trial were calculated from the motion analysis data to ensure the desired 20° or 50° flexion angle had been achieved.

In addition to the eight static normalisation tasks, three dynamic normalisation procedures were considered: a toe touch (TT) movement performed to a verbal time cue, and cycles of the lift-carry-lower-return (LCLR) work task (Section 2.4.).

2.4. Work task

A lift-carry-lower-return (LCLR) task was designed to simulate cyclic manual materials handling work. For each cycle, participants lifted a 10 kg box (no handles) from floor to knuckle level, walked 4.3 m, placed the box on a target on the floor, and walked 4.3 m back to the start location. The LCLR task had a cycle time of 15 s and 20 sequential repeats were performed.

2.5. EMG and posture recordings

EMG was collected bilaterally at three positions along the erector spinae (ES) muscles. Pairs of electrodes were placed 5 cm

laterally to ninth thoracic vertebrae (T9) (McGill, 1991), and 3 cm lateral to the first (Danneels et al., 2001) and fifth lumbar vertebrae (Macintosh and Bogduk, 1987) (L1 and L5, respectively). At each site, the skin was shaved, cleaned and abraded with alcohol prior to applying a disposable two snap Ag-AgCl electrode with a 2 cm inter-electrode distance (IED) (*Noraxon Dual Electrode, Scottsdale, Noraxon, Arizona, USA*). Electrodes were aligned with the predicted muscle fibre orientations according to De Foa et al. (1989). A single snap reference electrode (*Noraxon Single Electrode, Scottsdale, Noraxon, Arizona, USA*) was positioned atop the seventh or eighth thoracic vertebrae, depending on which was more prominent. Skin characteristics, key anatomical landmarks and electrode placements were noted on a participant-specific transparent sheet following electrode application on day 1, and the sheet was used on subsequent days to assist with electrode placement on subsequent experimental days.

Reflective markers (10 mm diameter - *Motion Analysis Corporation, Santa Rosa, California, USA*) were positioned over the estimated centre of rotation for the left shoulder and hip and tracked in real-time, providing trunk angle data – Fig. 2.

EMG signals were pre-amplified (gain 500) at a distance of 6.5 cm from the recording site; wireless signals were transmitted to the central receiver (*Noraxon TeleMyo 2400R, Noraxon, Scottsdale, Arizona, USA*) where they were band-pass filtered (10–500 Hz). Data were sampled at 1024 Hz and A/D converted through a 12 bit National Instruments A/D card. Data were monitored continuously throughout recording using EvaRT software (*Motion Analysis Corporation, Santa Rosa, California, USA*).

Motion data were captured using a system of ten infrared cameras (Eagle digital cameras - *Motion Analysis Corporation, Santa Rosa, California, USA*), sampled at 60 Hz, continuously monitored in real time and synchronised to EMG data and recorded in the EvaRT software.

2.6. Data processing

All data processing was done using custom software written in MatLab (Mathworks, Natick, Massachusetts, USA)
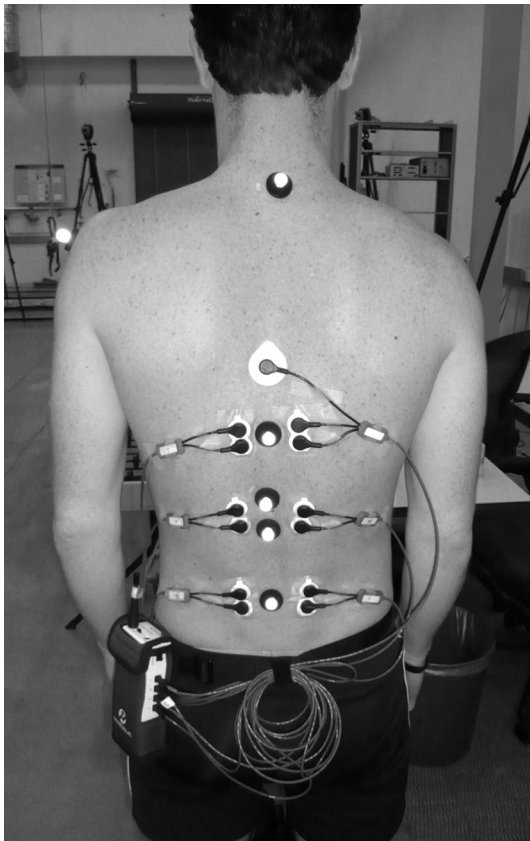
Fig. 2. Electromyography and motion capture marker set up.

2.6.1. Posture

Mean trunk flexion angles for all standing tasks were calculated as the angle between the vertical and the vector between the hip and shoulder markers.

2.6.2. EMG

Following collection, EMG signals were offset corrected, Butterworth filtered (30 Hz high-pass filter to minimize contamination from heart rate (Drake and Callaghan, 2006)), and RMS converted (moving window, 100 ms). The minimum rest value (2.5 s window) was identified across all rest trials and used to quadratically rest adjust all normalisation and work cycle trials (Jackson et al., 2009). All trials were inspected visually for data collection errors: no trials required removal from the data set. For all static normalisation tasks, the mean RMS EMG amplitude was then taken across each 10 s normalisation trial. For the TT$_{all}$ method, the mean RMS EMG amplitude was taken across the entire 10 s trial. For the TT$_{move}$ method, the mean was taken across only the moving portion of the trial. To identify the onset and completion of the TT movement tangential slopes to the trunk flexion/extension angular data curve were calculated and local minima and maxima were identified; all files were visually inspected to confirm the proper points had been selected. Finally, the mean value across single LCLR task cycles was calculated and used as normalisation quotient.

All 20 LCLR task cycles were normalised to each of the four repeats of each of the 11 normalisation tasks and for each cycle, the following exposure parameters were calculated: cumulative amplitude probability distribution function (APDF) values at the 1st, 10th, 50th, 90th and 99th percentiles. These metrics were chosen as they have often been used in EMG studies of ES muscle activity (Callaghan and McGill, 2001; Dunk and Callaghan, 2010;

Durkin et al., 2006; Graham et al., 2009; Koblauch, 1996; Nogueira et al., 2016; Wells et al., 1997; Village et al., 2005)

2.7. Analyses

All statistical analyses were performed using IBM SPSS Statistics for Windows (Version 22.0. Armonk, NY: IBM Corp).

2.7.1. Quantification of variance components

To quantify the unique component of variance attributable to subject, day, work cycle repeat, and normalisation task, variance component analyses were performed. For each of the 11 normalisation methods and 5 exposure parameters (APDF$_1$, APDF$_{10}$, APDF$_{50}$, APDF$_{90}$ or APDF$_{99}$) pooled data sets were formed across all subjects, days, cycles and normalisation repeats. The total variability of each data set was partitioned using a random effects model with crossed sub-factors (Searle et al., 2006) as follows:

$$E_{sdcn} = \mu + \alpha_s + \beta_{sd} + \gamma_{sdc} + \xi_{sdn} + e_{sdcn} \tag{1}$$

where E_{sdcn} is the experimental value of the exposure parameter obtained for subject, s, on day, d, for cycle, c, and sub-maximal normalisation task trial, n; μ is the grand mean across all s, d, c and n; α_s is the random effect of subject on the value of the exposure parameter for s = 1, 2, …, n_s; β_{sd} is the random effect of day within subject for d = 1, 2, …, n_d; γ_{sdc} is the random effect of cycle within day and subject for c = 1, 2, …, n_c; ξ_{sdn} is the random effect of normalisation task trial repeat within day and subject for n = 1, 2, …, n_n; and e_{sdcn} is the residual error term which includes the interaction between cycle and normalisation trial. All effects, α_s, β_{sd}, γ_{sdc}, ξ_{sdn} and e_{sdcn}, are assumed to be independently and identically distributed (i.i. d.), have zero covariance between any pair of values and to have a mean of zero:

$$\alpha_s \sim \text{i.i.d.}\ (0, \sigma_\alpha^2),\ \beta_{sd} \sim \text{i.i.d.}\ (0, \sigma_\beta^2),\ \gamma_{sdc} \sim \text{i.i.d.}\ (0, \sigma_\gamma^2),\ \xi_{sdn} \sim \text{i.i.} \\ \text{d.}\ (0, \sigma_\xi^2),\ \text{and}\ e_{sdcn} \sim \text{i.i.d.}\ (0, \sigma_e^2)$$

where σ_α^2, σ_β^2, σ_γ^2 and σ_ξ^2 are the true variance components for subject, day, cycle and normalisation trial, respectively.

For all models, estimates of the variance components for subject, day, cycle and normalisation trial, s^2_s, s^2_d, s^2_c and s^2_n, respectively, were calculated using ANOVA algorithms with Type III sums of squares selected in *IBM SPSS Statistics for Windows (Version 22.0. Armonk, NY: IBM Corp)* and custom syntax to define the appropriate nested and crossed effects model. ANOVA algorithms were selected given their good performance: (i) when the ratio of variance components between subjects to within subjects is larger than 1 (which was true for the majority of our exposure parameters), and (ii) for non-normally distributed (Kromhout et al., 1993; Rappaport, 1991) but "reasonably well balanced" data (Pitcher et al., 2008; Swallow and Monahan, 1984), as was true of the present data set. All negative estimates of variance (21 of the 1650 calculated values in the present data set) were replaced with zero values (Mathiassen et al., 2003; Searle et al., 2006).

Repeatability of normalisation tasks was assessed using coefficients of variation (CVs), which facilitate comparison between exposure parameters and normalisation tasks as well as with previously published data. CVs were calculated according to Eq. (2), where S_n^2 is the variance estimate from the pooled data set for the unique contribution of the given normalisation task, and m is the grand mean from the pooled data set for the APDF exposure parameter of interest (APDF$_1$, APDF$_{10}$, APDF$_{50}$, APDF$_{90}$ or APDF$_{99}$).

$$CV = \sqrt{S_n^2} * m^{-1} * 100\% \tag{2}$$

The proportion of the total exposure variance uniquely attributable to normalisation was calculated for each normalisation task both at the level of the group (Eq. (3)) and at the level of the

individual (Eq. (4)) to facilitate further comparison of the repeatability across normalisation tasks and to understand the magnitude of the error due to normalisation.

$$Percentage \ of \ variance_{group} = \frac{S_n^2}{S_s^2 + S_d^2 + S_c^2 + S_n^2} * 100\% \qquad (3)$$

$$Percentage \ of \ variance_{individual} = \frac{S_n^2}{S_d^2 + S_c^2 + S_n^2} * 100\% \qquad (4)$$

2.7.2. Stability of variance components

To assess the stability of variance component estimates, jack-knife simulations were conducted on APDF$_{50}$ data for all normalisation methods. For each normalisation task, one subject was removed from the data set at a time and variance components were re-calculated for the remaining data set. The ranges in magnitudes of all variance components and relative proportions of variance attributable to normalisation were then calculated across the 15 jack-knife data sets per exposure parameter and task.

2.8. Rating of normalisation tasks

The efficacy of the normalisation methods was assessed by scoring the CVs and proportions of variance for each normalisation task into four categories using the following grading system and criteria:

Top score - normalised data from *at least* 4 of the 5 APDF exposure parameters showed:

Proportion of variance – group level: Normalisation accounted for ≤5% of the total variance
Proportion of variance – individual level: Normalisation accounted for ≤10% of the total variance
Coefficient of variation: CVs ≤ 10%.

Good score - normalised data from 3 of the 5 APDF exposure parameters showed:

Proportion of variance – group level: Normalisation accounted for ≤5% of the total variance
Proportion of variance – individual level: Normalisation accounted for ≤10% of the total variance
Coefficient of variation: CVs ≤ 10%.

Moderate Score - The normalisation methods not falling into any of the other categories.
Bottom score - normalised data from *at least* 4 of the 5 APDF exposure parameters showed:

Proportion of variance – group level: normalisation accounts for ≥15% of the total variance
Proportion of variance – individual level: normalisation accounts for ≥20% of the total variance
Coefficient of variation: CVs ≥ 20%.

3. Results

3.1. Normalisation task EMG amplitudes and postures

In general, lumbar erector spinae (L1 & L5) EMG amplitude was highest during the prone normalisation task, which required participants to suspend the weight of their upper body; thoracic level erector spinae muscles were generally most active when standing at 50° hip flexion and suspending a 10 kg weight in the hands. These data are evident in the median task exposure measure amplitudes presented in Table 2 (bold values): for L1 and L5, the smallest value for APDF50 (%RVE) occurs for the prone task, meaning the prone normalisation reference amplitude (denominator value during normalisation) was the largest among all the normalisation tasks. For T9, the smallest value for APDF50 (%RVE) occurred for the Stand$_{50°}$ 10 kg task. Exposure data were similar for left and right recording sites, both in terms of magnitude and reliability; therefore, only data from the right side are presented throughout the remainder of the article.

For the Stand$_{20°}$ posture, the mean trunk angle (across all days and subjects) for the BW task was 18.2 (SD 1.9°), and 18.4 (SD 1.4°) for the 10 kg task. Stand$_{50°}$ posture tasks had a mean trunk angle of 47.5 (SD 1.6°) for the BW task, 46.4 (SD 2.2°) for the 10 kg task, and 45.7 (SD 1.5) for the EB task.

3.2. Variance components

For all normalisation tasks and exposure parameters, a unique component of variance was determined that was attributable to the methodological process of normalisation. A complete set of variance component estimates for the exposure parameter, APDF$_{50}$, is presented in Table 2. Since variance component magnitude is dependent on the magnitude of the measured variable, the mean exposure parameter values are also provided to facilitate comparison across normalisation tasks and exposure parameters.

The proportions of variance uniquely attributable to normalisation are presented at the level of the group (Table 3A) and the individual (Table 3B) for all outcome exposures and all normalisation tasks.

At the group level, the proportion of variance uniquely attributable to normalisation for the median exposure (APDF 50) was less than 5% for prone, seated, and the standing normalisation tasks performed at 20° flexion – Table 3A. The proportion tended to increase with increased exposure parameter amplitude, but only up to APDF 90 – Table 3A. The proportion of variance attributable to normalisation were considerably higher for tasks performed at 50° hip flexion compared with all other normalisation tasks.

At the level of the individual, the proportion of variance uniquely attributable to normalisation for the median exposure (APDF 50) was at or below 10% only when using the prone and neutral-posture seated normalisation tasks – Table 3B. Again, the proportion of variance uniquely attributable to normalisation tended to increase with increased exposure parameter amplitude, but only up to APDF 90 - Table 3B.

Coefficients of variation within day for the component of variance uniquely attributable to normalisation (s_n^2) were distinctly higher for standing trials performed at 50° trunk flexion (with and without the weight in the hands) compared with all other normalisation tasks, particularly at the two lumbar EMG recording sites – Table 4. For example, CVs for S_n^2 estimates for the prone RVE task were all less than or equal to 10%, whereas CVs for the standing RVE task at 50° flexion with a 10 kg mass in the hands ranged from 37 to 53%. Normalisation repeatability was better (i.e. lower CVs) for both lumbar recording sites than for the thoracic site – Table 4 (T9 rows compared to L1 and L5 rows).

3.3. Stability of variance components

Jack-knife simulation values are presented for all median APDF parameter data in Tables 2–4. At all three EMG recording sites, there was a great deal more uncertainty in estimates of variance, proportions of variance and coefficients of variance for the three standing tasks performed at 50° trunk flexion compared with any of the other normalisation tasks. CV values (Table 4) show EMG data from lumbar recording sites were not only more repeatable

Table 2

APDF$_{50}$ mean value and variance components showing the unique contribution of subject, day, cycle and normalisation to the total pooled variance for each of 11 sub-maximal normalisation tasks – see table 1 for description of normalisation tasks. Stability estimates for all variance component magnitudes from the jack-knife simulations (c.f. Section 2.7.2) are given in parentheses in italic text. Variance measured in %RVE^2.

APDF 50		Prone	Sit$_{0°}$ 30%MVF	Sit$_{20°}$ 30%MVF	Stand$_{20°}$ BW	Stand$_{20°}$ 10kg	Stand$_{50°}$ BW	Stand$_{50°}$ 10kg	Stand$_{50°}$ 10kg.EB	TT$_{ALL}$	TT$_{move}$	$\overline{LCLR}$
T9	$\overline{\chi}$ (%RVE)	57.5	94.8	96.4	106.8	57.9	58.5	**35.8**	38.5	104.2	81.6	34.8
	S^2s	680.0 *(264.5–754.5)*	3692.3 *(1143.0–4077.2)*	7310.2 *(2902.0–7930.6)*	3310.0 *(902.6–3598.9)*	1398.9 *(377.0–1515.9)*	1074.4 *(528.9–1178.4)*	449.1 *(155.7–489.0)*	291.2 *(128.6–324.7)*	2369.6 *(1620.9–2633.0)*	1831.7 *(1103.5–2035.7)*	147.9 *(141.0–175.8)*
	S^2_d	304.2 *(190.9–328.2)*	1253.7 *(938.4–1351.4)*	1237.0 *(711.9–1353.3)*	498.8 *(322.8–592.0)*	202.7 *(152.8–217.6)*	79.0 *(21.9–161.7)*	36.5 *(16.9–43.8)*	131.7 *(107.2–142.0)*	466.0 *(331.9–527.4)*	369.9 *(268.7–412.2)*	67.4 *(13.4–73.6)*
	S^2_c	395.5 *(241.8–424.0)*	1298.1 *(692.5–1389.9)*	1352.7 *(933.3–1447.2)*	2719.2 *(500.0–2907.7)*	491.8 *(208.7–525.2)*	674.6 *(140.0–721.2)*	92.4 *(65.3–98.2)*	102.5 *(79.7–109.1)*	1720.0 *(483.4–1837.2)*	1281.1 *(280.1–1368.7)*	56.8 *(50.1–59.6)*
	S^2n	74.3 *(53.5–79.5)*	281.7 *(205.6–301.1)*	536.6 *(196.4–573.8)*	169.3 *(139.9–180.5)*	88.9 *(49.6–95.2)*	225.5 *(41.1–241.5)*	38.4 *(23.4–41.1)*	41.8 *(23.6–44.8)*	273.2 *(203.9–291.3)*	206.3 *(132.8–220.2)*	8.8 *(8.0–9.3)*
	e	4.1 *(3.2–4.4)*	31.5 *(18.3–33-8)*	35.1 *(15.1–37.5)*	23.2 *(6.1–24.9)*	10.6 *(3.9–11.4)*	81.6 *(2.3–87.5)*	7.3 *(1.2–7.8)*	4.4 *(2.2–4.7)*	35.0 *(14.1–37.4)*	30.6 *(10.0–32.7)*	2.8 *(0.6–3.0)*
L1	$\overline{\chi}$ (%RVE)	**45.7**	95.8	81.9	89.3	64.8	101.7	63.6	63.9	107.9	81.0	59.7
	S^2s	152.8 *(102.2–171.2)*	1840.3 *(552.6–1987.5)*	847.7 *(624.7–927.7)*	184.1 *(118.8–219.7)*	242.5 *(146.6–266.3)*	0.0 *(0.0–663.2)*	141.8 *(75.9–270.9)*	6.0 *(0.0–205.0)*	504.3 *(221.3–602.4)*	313.6 *(250.5–399.9)*	161.1 *(133.5–175.3)*
	S^2_d	99.9 *(28.7–107.9)*	687.1 *(116.3–736.7)*	150.2 *(80.4–161.6)*	247.9 *(163.0–266.8)*	43.9 *(32.5–47.7)*	23902.4 *(1.0–25689.2)*	1892.7 *(90.3–2028.3)*	537.5 *(87.7–576.4)*	386.4 *(150.0–416.2)*	227.4 *(86.3–244.8)*	28.2 *(11.0–31.0)*
	S^2_c	34.1 *(31.2–35-8)*	165.6 *(139.4–174.1)*	113.1 *(99.8–118.5)*	148.8 *(134.8–157.4)*	74.4 *(67.4–78.2)*	1844.6 *(86.4–1974.4)*	220.1 *(46.9–234.2)*	110.3 *(57.1–116.6)*	207.6 *(189.4–217.0)*	116.3 *(105.4–122.0)*	56.5 *(52.1–59.4)*
	S^2n	14.1 *(11.2–15.1)*	46.2 *(32.3–49.1)*	48.4 *(28.8–51.7)*	65.0 *(49.4–69.1)*	10.1 *(9.3–10.8)*	2759.2 *(218.8–2956.0)*	556.9 *(45.4–596.6)*	888.8 *(17.7–952.0)*	94.1 *(63.4–100.3)*	43.6 *(31.9–45.8)*	15.0 *(12.4–15.9)*
	e	0.2 *(0.1–0.2)*	0.9 *(0.6–0.9)*	0.4 *(0.4–0.5)*	0.8 *(0.7–0.9)*	0.2 *(0.2–0.2)*	168.3 *(1.9–180.3)*	33.6 *(0.6–36.0)*	57.0 *(0.2–61.1)*	1.2 *(1.0–1.3)*	0.6 *(0.6–0.7)*	0.2 *(0.2–0.3)*
L5	$\overline{\chi}$ (%RVE)	**40.8**	132.5	89.4	92.3	64.7	122.8	80.3	74.2	109.1	82.2	52.2
	S^2s	246.2 *(189.3–267.5)*	2759.3 *(2266.6–3116.9)*	1527.4 *(948.8–1673.8)*	488.9 *(312.0–567.0)*	367.9 *(280.5–397.6)*	0.0 *(0.0–2266.7)*	1643.0 *(317.3–1848.7)*	0.0 *(0.0–361.2)*	704.3 *(540.2–780.3)*	637.3 *(518.2–715.1)*	186.5 *(150.2–202.4)*
	S^2_d	64.2 *(33.4–69.5)*	1820.7 *(1527.1–1958.9)*	484.6 *(344.9–519.4)*	233.4 *(161.5–253.5)*	39.9 *(28.1–44.0)*	60903.0 *(0.0–65441.0)*	20298.7 *(99.1–21749.0)*	6090.6 *(160.6–6526.0)*	325.3 *(264.8–350.9)*	210.6 *(155.2–226.7)*	39.7 *(31.3–43.5)*
	S^2_c	33.1 *(28.3–34.9)*	449.4 *(343.0–478.5)*	162.4 *(134.3–171.4)*	181.7 *(172.3–192.5)*	85.3 *(77.4–90.1)*	4763.5 *(130.1–5101.6)*	1799.1 *(48.9–1926.6)*	575.5 *(61.8–615.4)*	233.8 *(123.5–246.7)*	132.3 *(113.0–139.7)*	48.6 *(44.6–51.0)*
	S^2n	10.8 *(8.9–11.5)*	203.0 *(153.2–217.2)*	68.6 *(18.4–73.4)*	70.5 *(61.4–74.5)*	20.8 *(16.0–22.3)*	3991.4 *(2088.6–4276.5)*	1193.9 *(39.0–1278.9)*	9353.6 *(12.0–10021.5)*	94.1 *(74.8–100.2)*	42.9 *(32.0–45.9)*	8.7 *(7.8–9.2)*
	e	0.2 *(0.2–0.2)*	5.5 *(3.6–5.9)*	0.7 *(0.5–0.7)*	1.4 *(1.3–1.5)*	0.4 *(0.4–0.5)*	166.7 *(30.4–178.7)*	69.9 *(0.7–74.9)*	667.4 *(0.2–715.1)*	1.6 *(1.4–1.7)*	0.8 *(0.6–0.8)*	0.2 *(0.1–0.2)*

Table 3
(A + B) - Relative proportions of variance uniquely attributable to normalisation at **(A)** the **level of the group** – Eq. (3), and **(B)** the **level of the individual** – Eq. (4). Proportions ≤ 5% (group) and 10% (individual) of the total variance shown in bold. Stability estimates from the jack-knife simulations (c.f. Section 2.7.2) are given in parentheses in italic text for the median measures (APDF 50).

(A)

APDF		Prone	$Sit_{0°}$ 30%MVF	$Sit_{20°}$ 30%MVF	$Stand_{20°}$ BW	$Stand_{20°}$ 10kg	$Stand_{50°}$ BW	$Stand_{50°}$ 10kg	$Stand_{50°}$ 10kg.EB	TT_{ALL}	TT_{move}	$\overline{LCLR}$
T9	1	**1.3**	**0.8**	**1.7**	**2.1**	**1.9**	**1.7**	**1.9**	**1.3**	**1.1**	**2.4**	**0.8**
	10	**4.1**	**3.0**	**4.7**	**3.3**	**2.7**	**3.3**	**2.3**	**2.8**	**3.1**	**4.1**	**1.1**
	50	5.1	**4.3**	5.1	**2.5**	**4.1**	11.0	6.2	7.4	5.7	5.6	**3.1**
		(4.3–6.4)	*(3.4–7.4)*	*(4.1–5.7)*	*(2.1–6.7)*	*(3.8–4.9)*	*(4.7–12.6)*	*(3.7–11.7)*	*(6.7–8.2)*	*(4.3–8.5)*	*(4.4–9.1)*	*(2.7–6.2)*
	90	3.9	5.8	6.2	**1.9**	5.5	17.2	23.7	15.0	5.1	5.2	12.6
	99	2.9	4.4	5.1	**1.4**	4.0	15.5	29.6	15.9	**3.2**	**3.5**	10.9
L1	1	**0.3**	**0.2**	**0.5**	**0.4**	**0.4**	4.5	6.6	13.4	**0.2**	**0.4**	**0.5**
	10	**1.3**	**0.8**	**1.6**	**2.0**	**0.9**	8.4	15.7	44.5	**1.1**	**1.1**	**1.2**
	50	**4.7**	**1.7**	**4.2**	10.1	**2.7**	9.7	19.8	57.6	7.9	6.2	5.8
		(3.9–6.4)	*(1.5–3.8)*	*(3.1–5.3)*	*(8.4–11.4)*	*(2.4–3.6)*	*(9.1–22.6)*	*(10–20.3)*	*(4.8–58.8)*	*(6.2–9.4)*	*(5.0–6.9)*	*(5.3–6.6)*
	90	11.8	**3.0**	7.2	16.9	9.6	9.5	21.1	59.8	16.6	15.8	34.2
	99	10.3	**3.3**	7.3	13.0	**5.0**	9.2	19.5	57.8	12.2	11.5	14.9
L5	1	**0.4**	**0.9**	**0.4**	**0.4**	**0.3**	**1.8**	4.6	38.7	**0.5**	**0.6**	**0.3**
	10	**1.2**	**2.3**	**1.8**	**1.7**	**1.0**	**3.2**	4.5	56.2	**1.4**	**1.3**	**0.8**
	50	**3.0**	**3.9**	**3.1**	7.2	**4.1**	5.7	**4.8**	58.4	6.9	**4.2**	**3.1**
		(2.6–3.5)	*(2.9–4.4)*	*(1.2–3.8)*	*(6.1–9.0)*	*(3.0–5.1)*	*(2.9–47.9)*	*(4.7–7.7)*	*(2.0–58.5)*	*(5.3–8.1)*	*(3.4–4.9)*	*(2.7–3.6)*
	90	13.8	**3.6**	**2.9**	8.5	5.9	**4.4**	**4.8**	59.2	13.5	12.3	31.1
	99	9.9	**3.6**	**2.8**	6.2	**3.9**	**3.6**	**4.4**	58.5	8.5	7.9	14.2

(B)

APDF		Prone	$Sit_{0°}$ 30%MVF	$Sit_{20°}$ 30%MVF	$Stand_{20°}$ BW	$Stand_{20°}$ 10kg	$Stand_{50°}$ BW	$Stand_{50°}$ 10kg	$Stand_{50°}$ 10kg.EB	TT_{ALL}	TT_{move}	$\overline{LCLR}$
T9	1	**3.1**	**1.7**	**3.6**	**5.0**	**3.8**	**3.2**	**3.5**	**2.5**	**2.2**	**4.6**	**1.4**
	10	**4.8**	**5.7**	**7.9**	**4.8**	**4.9**	**4.5**	**4.1**	**4.3**	**4.3**	**5.6**	**1.9**
	50	**9.6**	**9.9**	17.2	**5.0**	11.3	23.0	22.9	15.2	11.1	11.1	**6.6**
		(8.3–12.4)	*(7.5–14.1)*	*(10.7–19.5)*	*(4.0–11.6)*	*(7.8–16.5)*	*(12.0–24.7)*	*(16.3–26.6)*	*(10.5–17.2)*	*(8.4–19.9)*	*(8.7–22.0)*	*(5.8–11.7)*
	90	11.3	10.4	29.1	13.5	16.9	72.6	66.7	25.9	24.4	22.8	14.9
	99	**9.1**	**7.7**	32.1	**9.3**	12.6	73.3	78.1	25.9	15.6	14.6	17.8
L1	1	**0.5**	**0.4**	**0.8**	**0.7**	**0.7**	4.6	7.3	15.5	**0.4**	**0.5**	**0.8**
	10	**3.1**	**2.2**	**3.8**	**4.9**	**2.3**	8.7	18.3	52.3	**2.7**	**2.6**	**3.4**
	50	**9.5**	**5.1**	15.5	14.1	**7.9**	9.7	20.9	57.8	13.7	11.3	15.0
		(7.6–15.3)	*(4.7–10.7)*	*(9.4–19.6)*	*(12.4–15.4)*	*(7.0–8.5)*	*(9.1–71.5)*	*(20.5–24.9)*	*(10.9–59.0)*	*(12.3–15.1)*	*(9.7–13.3)*	*(12.5–18.2)*
	90	18.2	14.9	21.1	19.6	11.5	**9.5**	21.1	59.8	19.6	18.9	39.8
	99	13.5	12.2	14.7	13.6	**6.8**	9.2	20.0	57.8	14.1	13.5	20.5
L5	1	**1.0**	**1.6**	**0.8**	**0.5**	**0.4**	**1.9**	5.7	44.5	**0.6**	**0.8**	**0.5**
	10	**5.2**	**9.3**	**9.9**	**5.5**	**4.1**	**3.2**	**5.1**	58.4	**4.1**	**4.1**	**3.7**
	50	**10.0**	**8.2**	**9.6**	14.5	14.3	5.7	**5.1**	58.4	14.4	11.1	**8.9**
		(8.6–11.9)	*(6.8–9.2)*	*(3.0–12.1)*	*(12.4–17.9)*	*(11.3–15.5)*	*(2.9–94.4)*	*(5.0–20.9)*	*(5.1–58.5)*	*(11.6–16.3)*	*(8.6–12.9)*	*(7.7–9.9)*
	90	39.1	13.8	15.0	16.9	15.8	**4.4**	**5.2**	59.2	21.4	19.8	44.2
	99	19.2	13.3	11.5	10.3	**7.7**	**3.6**	**4.8**	58.5	13.4	12.1	16.9

Table 4
Coefficients of variation (CVs) showing the percent variance uniquely attributable to normalisation (S^2n - Table 2) for APDF exposure parameters. CVs ≤ 10% shown in bold. Stability estimates from the jack-knife simulations (c.f. Section 2.7.2) are given in parentheses in italic text for the median measures (APDF 50).

APDF		Prone	$Sit_{0°}$ 30%MVF	$Sit_{20°}$ 30%MVF	$Stand_{20°}$ BW	$Stand_{20°}$ 10kg	$Stand_{50°}$ BW	$Stand_{50°}$ 10kg	$Stand_{50°}$ 10kg.EB	TT_{ALL}	TT_{move}	$\overline{LCLR}$
T9	1	20.7	18.9	27.4	26.5	25.4	24.7	25.6	20.9	19.1	29.1	15.7
	10	15.6	16.8	20.2	15.5	15.5	16.6	14.5	15.9	16.0	19.6	**9.8**
	50	15.0	17.7	24.0	12.2	16.3	25.7	17.3	16.8	15.9	17.6	**8.5**
		(12.7–15.5)	*(15.1–18.3)*	*(14.5–24.8)*	*(11.1–12.6)*	*(12.2–16.8)*	*(11.0–26.6)*	*(13.5–17.9)*	*(12.6–17.4)*	*(13.7–16.4)*	*(15.6–18.2)*	*(8.1–8.8)*
	90	12.2	18.9	22.9	13.7	18.2	40.7	25.0	18.3	17.9	20.9	10.0
	99	12.7	20.7	22.9	15.4	20.7	52.5	31.9	21.0	19.4	23.2	11.0
L1	1	**9.4**	**7.5**	11.3	10.2	10.4	69.0	53.1	66.5	**8.0**	**9.9**	11.7
	10	**7.5**	**6.3**	**8.2**	**9.5**	**6.2**	72.6	56.8	76.3	**7.1**	**7.2**	**7.1**
	50	**8.2**	**7.1**	**8.5**	**9.0**	**4.9**	51.6	37.1	46.6	**9.0**	**8.2**	**6.5**
		(7.3–8.5)	*(5.9–7.3)*	*(6.6–8.8)*	*(7.9–9.3)*	*(4.7–5.1)*	*(14.5–53.5)*	*(10.6–38.4)*	*(6.6–48.3)*	*(7.4–9.3)*	*(7.0–8.4)*	*(5.9–6.7)*
	90	**7.4**	**6.8**	**7.2**	**8.1**	**5.0**	54.2	39.6	50.1	**8.2**	**7.6**	**6.4**
	99	**7.3**	**6.9**	**7.2**	**8.1**	**5.0**	59.3	44.3	56.9	**8.0**	**7.5**	**6.6**
L5	1	10.1	14.4	10.3	**8.8**	**8.3**	44.9	64.2	160.4	**9.5**	10.6	**7.3**
	10	**8.5**	12.3	11.9	**8.6**	**7.0**	49.8	54.7	177.6	**7.6**	**7.7**	**6.2**
	50	**8.0**	10.7	**9.3**	**9.1**	**7.1**	51.5	43.0	130.4	**8.9**	**8.0**	**5.6**
		(7.3–8.3)	*(9.3–11.1)*	*(4.8–9.6)*	*(8.5–9.3)*	*(6.2–7.3)*	*(37.2–53.3)*	*(7.8–44.5)*	*(4.7–134.9)*	*(7.9–9.2)*	*(6.9–8.2)*	*(5.3–5.8)*
	90	**7.6**	11.9	**7.6**	**8.9**	**6.8**	49.2	47.2	146.9	**8.5**	**7.8**	**5.9**
	99	**7.4**	11.6	**7.4**	**8.8**	**6.8**	51.5	52.9	173.8	**8.5**	**8.0**	**6.0**

Table 5
Summary of normalisation task ratings. Tasks arranged from left to right in groups with descending order of efficacy. Group are based on the overall general impression of each normalisation task's efficacy across all exposure parameters and all EMG recording sites according to the grading criteria outlined in Section 2.8.

		Prone	Stand₂₀° 10Kg	Sit₂₀° 30%MVF	Sit₀° 30%MVF	$\overline{LCLR}$	Stand₂₀° BW	TT_ALL	TT_move	Stand₅₀° BW	Stand₅₀° 10Kg	Stand₅₀° 10Kg_EB
T9	%var Group											
	%var IND											
	CV											
L1	%var Group											
	%var IND											
	CV											
L5	%var Group											
	%var IND											
	CV											

Legend: ☐ top score ▦ moderate score ▨ good score ■ bottom score

(lower CVs) but also more stable than thoracic EMG data for all normalisation methods investigated. Of the variance components investigated, estimates of the proportion of variance due to normalisation tended to be the most stable; for example, for the prone normalisation task, the range in proportions of total group variance attributable to normalisation was less than or equal to 2.5% at all EMG recording sites (Table 3A), whereas the proportions of total variance attributable to subject ranged from 6 to 25% depending on the recording site.

3.4. Normalisation task ratings

Outcome exposure parameters from Tables 3 and 4 were scored per the criteria outlined in Section 2.8. and a visual representation of the final scores (across all exposure parameters) is presented in Table 5.

Considering all exposure parameters and all recording sites, a general impression emerged of the overall efficacy of each normalisation task. The tasks fell into four groups which are shown in Table 5 in descending order of efficacy from left to right. The prone normalisation task had higher overall scores than any of the other methods, suggesting it was the best overall normalisation task – Table 5. Looking to the right side of Table 5, three normalisation tasks were easily distinguishable as having the worst repeatability indices, namely, all three standing tasks performed at 50° trunk flexion.

4. Discussion

Trunk muscle EMG signals have most often been normalised using MVEs (Mirka, 1991), however sub-maximal RVEs have shown increased sensitivity for assessing low levels of muscle activity (Allison et al., 1998; O'Sullivan et al., 2002; Snijders et al., 1995), are more repeatable (McGill, 1991; O'Sullivan et al., 2002) as well as more feasible (Pitcher et al., 2008) and preferable (Dankaerts et al., 2004) for clinical low back pain (CLBP) patients, and may even be more repeatable than maximal exertions (Yang and Winter, 1984). The lack of a commonly accepted RVE, and thus a common measurement scale to permit comparison, is a current limitation to this approach and motivated the present study.

To differentiate between normalisation tasks from the perspective of minimising variance, a custom set of criteria were developed for assessing task proportion of variance and CV values and each test was scored. The criteria attempted to balance (i) the per-

formance of each task across the five exposure parameters (often tasks were best for lower to mid-range amplitude metrics) and (ii) the performance of each task across the three sites measured (often thoracic level repeatability was inferior to lumbar level signal repeatability). The selected cut-off points for both the proportions of variance and the CVs seemed reasonable both from the sense of being feasible (based on previously published data), and when considering what magnitude of error could acceptably be introduced to a data set. Good normalisation CV values have commonly been reported in the range from 6 to 15% (for example: (Attebrant et al., 1995; Bao et al., 1995; Nordander et al., 2004; Veiersted, 1991)), thus supporting a top score criterion of CVs ≤ 10%. The 5% cut-off for top-scoring tasks for the unique contribution of variance due to normalisation to the total group level variance is supported by previous research showing similar values for a well-accepted task used in trapezius muscle normalisation (Jackson et al., 2009). The acceptable magnitude of induced error will, of course, vary with the research question. If very small changes of amplitude are expected in the exposure parameter(s) of interest, less error may be acceptable. For example, previous studies of seated office work have dealt with group differences less than 3% MVE (for example (Callaghan and Dunk, 2002; Kingma and van Dieen, 2009): such small changes would be more sensitive to a lack in measurement precision which would diminish the probability of determining significant differences (Armstrong, 1998; Mathiassen et al., 2002; Mathiassen et al., 2003; Thomas et al., 1993).

Normalisation tasks were subsequently grouped based on their scores. Since thoracic level EMG was clearly less repeatable for nearly all normalisation tasks, lumbar site EMG scores were more heavily weighted when forming the groups. From the perspective of minimising variance, the *prone* task was deemed superior to all other methods as it contained no bottom scores, and was the only task which had top scores for group level variance and CVs at both lumbar recording sites. Four tasks (*Sit₂₀° 30%MVF, Sit₀° 30%MVF, Stand₂₀° 10kg, $\overline{LCLR}$*) comprised a group that had slightly lower overall scores than the prone task, but that could still be considered optimal for use depending on the study goals. For example, if normalisation of thoracic level EMG was not involved and only group level outcome measures were of interest, the *Stand₂₀°* normalisation task could be a viable option from the perspective of minimizing variance. However, moving towards a common sub-maximal normalisation task in future studies would be beneficial to permit direct comparison and meta-analysis of EMG data. Three

tasks ($Stand_{50°}BW$, $Stand_{50°}$ 10kg, $Stand_{50°}$ 10kg.EB) comprised a bottom group which are not recommended for use in future studies.

To achieve repeatability and comparability, we asked participants to perform the static normalisation task postures using only hip flexion while maintaining a neutral lumbar curvature. Participants received training in flexing at the hip versus lumbar flexion, and practiced hip flexion and all normalisation tasks until they felt comfortable. The data presented in this paper are likely representative of the highest levels of repeatability and thus lowest estimates of induced methodological error one could expect. It is possible that the increased variance attributable to normalisation seen in the thoracic region EMG exposures is due to less strict control over vertebral posture in this region. It should therefore also be noted that lumbar region normalisation is potentially at risk of decreased repeatability in the absence of strong postural guidelines, such as those employed in the current study.

EMG data are time consuming and costly to collect, thus careful study planning and resource allocation is paramount to ensure sufficient precision in outcome exposure measures. The variance component data presented in this study (both in Table 2) can be used in concert with precision algorithms to determine the numbers of subjects, days, work cycles and normalisation trial repeats required to best suit the aim of a study by balancing the trade-offs between increased time and effort during data collection and decreased precision in outcome exposure metrics (c.f. (Jackson et al., 2009) – Eq. (6) (group level) or Eq. (7) (individual level)). The variance component data can also be used to calculate intra-class correlation coefficients (ICCs). ICCs are essentially a ratio of variances to measure the reliability of a study design which is affected by different sources of random error; one typical ICC is the ratio of 'true' between-subjects variance in a study to the total variance (including all random error components). ICCs have been commonly computed in previous studies considering normalisation task reliability, both for the purpose of examining reliability in studies wanting to distinguish between subjects, and also from a clinical perspective for studies considering the extent to which a specific subject repeats herself between days (de Vet et al. 2006). However, in order to quantify and compare the unique components of variance contributed by each factor (subject, day, work cycle and normalisation task, in the present study), variance component analyses are required, and thus used in the present study.

Three dynamic tasks were considered as interesting comparisons with the range of isometric trials. All ranked at a higher level of precision than the three standing trials performed at 50° trunk flexion, and the mean work cycle amplitude task scored in the next best group. However, work cycle amplitude will differ between studies, thus limiting comparability due to the lack of a common measurement scale. Further, the physiological significance of these dynamic tasks is difficult to interpret.

When using surface EMG to assess activity level of the erector spinae muscles, some contribution to the net signal may come from other overlying or surrounding muscles; for example, the trapezius muscle (T9 level recording site) or deeper level spinal muscles (all recording sites). We tried to minimise contributions from other muscles by selecting potential normalisation tasks specific to the action of the ES muscles. Further, we tried to minimise variance due to any additionally contributing muscles by strictly defining posture during each normalisation task.

While we have focused on minimising variance, other factors will also influence normalisation task selection. For example, one might desire a static or dynamic task; the study population may or may not be capable of performing true maximal contractions (for example, a clinical LBP population); and equipment availability must be considered (for example, a dynamometer is required for the seated tasks investigated in this study, and a bench for the prone task). If equipment or physical capacity are lacking,

potential tasks will be eliminated. To date, trunk extensor muscle normalisation has most commonly been performed prone using isometric extension exertions: while tasks have varied slightly, most are based on the Biering-Sørensen test posture (Biering-Sørensen, 1984). Previous studies have shown excellent repeatability for this posture among low back pain patients (Dankaerts et al., 2004; Pitcher et al., 2008), even if specific variance components are not, to date, available for this population. Paired with the relatively low equipment requirement and the high precision found for this method in the current study – lower body supported, legs strapped down in two locations, arms folded across the chest, and a subject-specific bar set across the scapulae to aid in posture maintenance – we recommend that this task be used in future studies of lumbar region erector spinae muscles employing a sub-maximal normalisation approach. An additional normalisation task specific to the function of the thoracic level ES muscles may be warranted from the perspective of minimizing methodological variance. One test that could be considered is an upper back extension effort in which subjects begin lying prone, then extend the upper back and lift the chest and shoulders off the supporting surface.

5. Conclusion

The unique contribution of normalisation to the overall variance of EMG exposure parameter metrics was calculated for eleven sub-maximal normalisation tasks (eight static, three dynamic). Normalisation tasks were scored according to their relative contribution to the overall exposure variance, and on their coefficients of variation. Tasks were then divided into groups based on their scores to provide decision support when selecting normalisation practices. The *prone* sub-maximal task was the best overall normalisation task: it was the most repeatable at all three EMG locations (erector spinae EMG was measured at T9, L1 and L5) and across all exposure parameters ($APDF_1$, $APDF_{10}$, $APDF_{50}$, $APDF_{90}$ or $APDF_{99}$). It is recommended that the *prone* normalisation task be utilised in future EMG studies employing sub-maximal reference contractions. Standing normalisation tasks performed at 50° trunk flexion proved to be the least repeatable. Thoracic level EMG was generally less repeatable than for the lumbar EMG recording sites for all normalisation tasks; an alternate normalisation task specific to the function of the thoracic level ES muscles may be warranted.

Conflict of interest

The authors declared that there is no conflict of interest.

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